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EFFECT OF CYCLIC WAVEFORMS WITH SUPERIMPOSED HIGH FREQUENCY FLUTTER ON THE CORROSION FATIGUE BEHAVIOUR OF A SUBMARINE HULL STEEL

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In the past, several investigators [1-4] have reported changes in the stress corrosion cracking or corrosion fatigue behaviour when small amplitude high frequency flutter loading was superimposed on a static load or the hold portion of cyclic waveform. In a more recent study [5], it was reported that in the presence of seawater the fatigue life (basic trapezoidal cycles) decreased when the superimposed flutter frequency increased from 1 Hz to 20 Hz. Above 20 Hz, and up to 30 Hz at least, no further frequency dependence was observed.

The significance of the past findings are of considerable practical importance especially dealing with a new steel (Australian designation BIS 812 EMA) for a submarine pressure hull application. It is recognised that a low frequency trapezoidal waveform is a useful approximation to the cyclic stresses experienced by a submarine during diving manoeuvres. The present work aims to elucidate the separate contributions of the ramp up/down and the hold components in the trapezoidal waveform. Tests in seawater were conducted using a triangular waveform and a continuous hold loading. High frequency flutter representing hull vibrations was superimposed on these basic loading profiles, and the results are reported as cycles or time to failure, i.e. fracture of the specimen.

Figure 1 illustrates the loading profiles used. The ramp rate in the triangular waveform (Fig. 1a) was identical to that in the trapezoidal waveform, giving a cyclic frequency of 0.075 Hz which is five times that of the trapezoidal waveform described in [5]. The frequency of the flutter was varied from 1 Hz to 30 Hz while its amplitude was maintained constant at $\pm$60 MPa in all tests. When combined, the maximum stress level in all tests was 422 MPa or 0.6 of the nominal yield stress of the steel. The specimen geometry and test conditions were the same as described previously [5].

Results are present in Figs. 2 and 3, and these are compared with the results obtained previously under a trapezoidal waveform [5]. In Fig. 2, the results obtained using the triangular waveform are compared with those obtained under a trapezoidal waveform in terms of number of cycles to failure. This comparison showed that the trapezoidal is more damaging, by a factor of 3, throughout the whole range of flutter frequencies.

In another comparison, test results obtained using a continuous hold loading profile are compared with the trapezoidal waveform results on the basis of time-to-failure in Fig. 3. Doing this, a remarkably close agreement was found over the whole range of flutter frequencies.

Any interpretation of the observed behaviour must pay due regard to the frequency of flutter, the basic loading profile, and how their different combinations affect crack initiation life (N_i) and crack propagation life (N_p). In two separate tests completed in seawater under trapezoidal waveform only (maximum stress 422 MPa), the total fatigue life (N_t) and N_i defined when a surface crack attained a length of 200 μm) were 130,468 cycles and 67,066 cycles respectively; superimposition of flutter (30 Hz) reduced N_t to 17,897 cycles (datum point in Fig. 2). Comparison of these results shows N_t (no flutter) was over seven times greater than N_t (with flutter). Furthermore, crack initiation life (no flutter) alone was almost four times greater than the total life in the presence of flutter. Further tests are planned to separate out the effects of flutter on N_i and N_p.

As an indirect approach to study the effect of flutter on the crack propagation stage, fracture surfaces of specimens failed in the above tests were examined and cracking morphologies were identified. Generally, a ductile transgranular crack propagation mode showing no influence of environment resulted in increased life, and was observed for loading profiles - trapezoidal with 0 Hz flutter, triangular with 5 Hz flutter and continuous hold with 5 Hz flutter.

Decreased life resulted when the crack propagation mode showed regions of brittle intergranular facets. Such a behaviour was observed at high frequency flutter (30 Hz) superimposed on the trapezoidal shape and continuous hold loading profiles. The appearance of intergranular facets on the fracture surface may suggest an embrittling mechanism operating as a result of complex mechanical/environmental interactions at the crack tip. The role of high frequency cyclic flutter may have influenced the kinetics in the crack tip region by freeing up rapidly any chemical impediments, and exposing fresh crack surface. This condition and the fact that the crack tip was held open under the action of high tensile stress, may have offered a greater opportunity for the generation and diffusion of embrittling species such as atomic hydrogen.

A third crack propagation mode observed was found to be dominance at high frequency flutter (30 Hz) superimposed on the triangular loading profile, and at low frequency flutter (5 Hz) superimposed on trapezoidal shape loading profile. This cracking mode, identified here as environment-controlled ductile transgranular mode, showed low level of embrittlement and as a consequence of this lives were less severely affected. Results shown in Figs. 2 and 3 correspond well with the observed differences in the fracture morphology.

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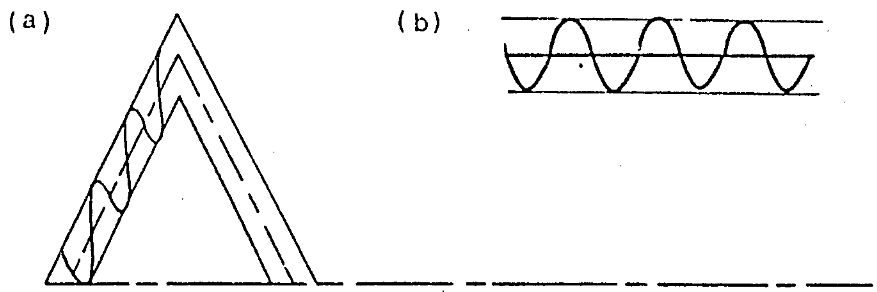

Figure 1. Loading profiles comprising flutter superimposed on (a) triangular waveform and (b) continuous static hold loading.

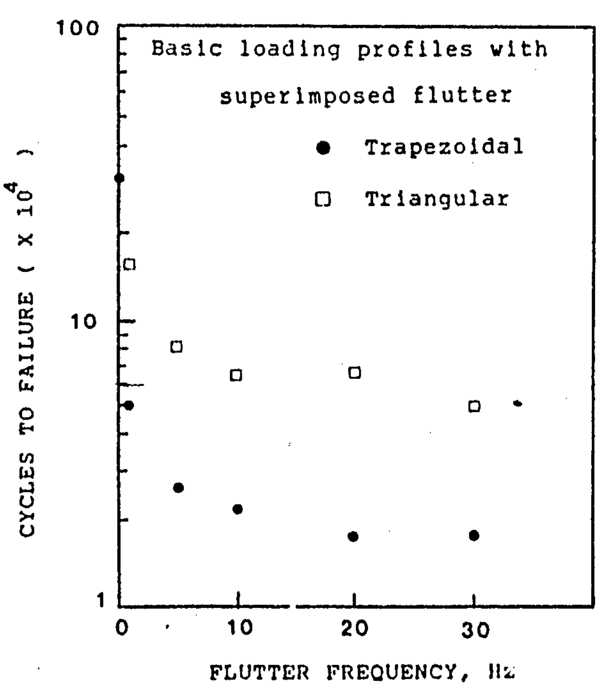

Figure 2. Effect of basic loading profiles on the flutter frequency dependency of the fatigue life of the BIS 812 EMA steel.

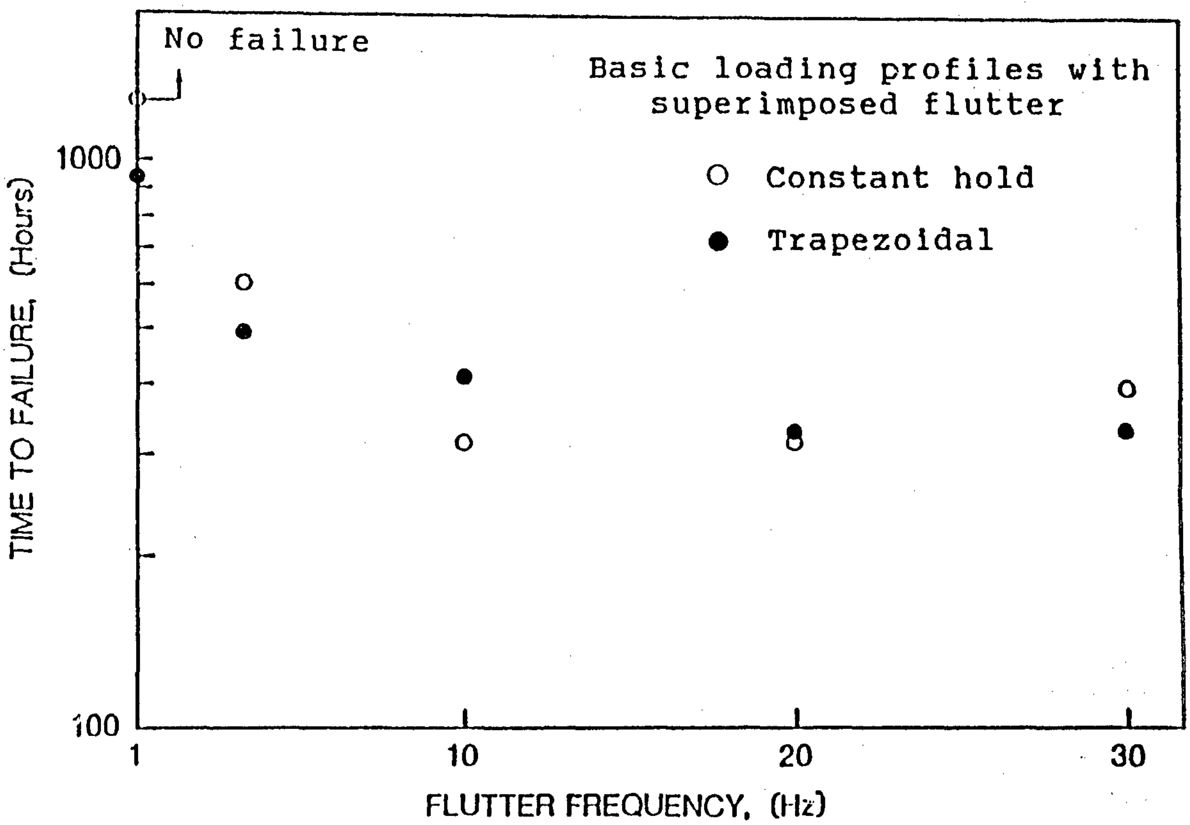

Figure 3. Effect of basic loading profiles on the flutter frequency dependency of time-to-failure of the BIS 812 EMA steel.